3.7. Hydrogen Safety

Safe practices in the production, storage, distribution, and use of hydrogen are essential components of a hydrogen economy. A catastrophic failure in any hydrogen project could irreparably damage the entire transition strategy. The Safety program element delineates the steps that the Hydrogen, Fuel Cells & Infrastructure Technologies Program is taking to ensure that its projects are performed in a safe manner.

Like all fuels, hydrogen can be handled and used safely with appropriate sensing, handling, and engineering measures. Hydrogen is a potentially dangerous substance because its low volumetric energy density requires high pressure and liquid storage to provide the same customer qualities, such as vehicle range and power density. However, its risk level as a fuel at atmospheric pressure is similar to that of fuels such as natural gas and propane. Hydrogen has unique properties because of its size and buoyancy. The aim of this program element activity is to verify the physical and chemical properties of hydrogen, outline the factors that must be considered to minimize the safety hazards related to the use of hydrogen as a fuel, and provide a comprehensive database on hydrogen and hydrogen safety.

3.7.1 Goal and Objectives

Goal

Develop and implement the practices and procedures that will ensure safety in the operation, handling, and use of hydrogen and hydrogen systems for all DOE-funded projects.

Objectives

- Draft a comprehensive safety plan to be completed in collaboration with industry. The plan will initiate the research necessary to fill safety information gaps and enable the formation of a Safety Review Panel, by 2004.

- Integrate safety procedures into all DOE project funding procurements. This will ensure that all projects that involve the production, handling, storage, and use of hydrogen incorporate project safety requirements into the procurements, by 2005.

- Publish a handbook of Best Management Practices for Safety by 2010. The Handbook will be a "living" document that will provide guidance for ensuring safety in future hydrogen endeavors.

3.7.2 Safety Risk Assessment

The successful completion of a hydrogen project requires the integration of safety at the earliest stages. Beginning with a project's planning stages, efforts must be made to identify and reduce or eliminate safety hazards. Systematic procedures must be used to consider design modifications and alternatives to reduce risks when hazards are identified, and should include mitigation (such as passive and active ventilation) in the case of unforeseen circumstances. Thus, the safety plan calls for inclusion of safety requirements in each program solicitation, a preliminary safety analysis in each proposal, and the inclusion of a complete safety analysis in Phase I of each project that includes the requirements of the Occupational Safety and Health Administration (OSHA1910.119).

For the purposes of this plan, the DOE Program has used the properties of hydrogen shown in Table 3.7.1 and compared them to other common fuels natural gas, gasoline, and liquified petroleum gas (LPG).

Table 3.7.1. Properties of Fuels

	Hydrogen	Natural Gas	Gasoline	LPG
Lower heating value (BTU/lb) (MJ/kg)	51,532 123	21,300 51	18,000 – 19,000 43 – 45	19,800 47
Higher heating value (BTU/lb) (MJ/kg)	61,002 145	23,600 56	18,800 – 20,400 45 – 49	21,600 51
Density at standard conditions (lb/gal) (kg/l)	0.0007[a] 0.00008	0.005[a] 0.0006	6.0 – 6.5 0.72 – 0.78	4.22 0.51
Phase at standard conditions	gas	gas	liquid	liquid
Autoignition temperature[b] in air (°F) Autoignition temperature in air (°C)	1,050 – 1,080 566 – 582	1,004 540	495 257	850 – 950 454 – 510
Ignition limit[c] in air (vol %)	4.1 – 74	5.3 – 15	1.4 – 7.6	2.2 – 9.5
Diffusion coefficient[d] in air (in^2/s) Diffusion coefficient in air (cm^2/s)	0.0946[e] 0.61	0.0248[e] 0.16	0.008[e] 0.05	0.017[f] 0.11

[a] Clean Air Program: Design Guidelines For Bus Transit Systems Using Hydrogen As an Alternative Fuel. U.S. Department of Transportation. DOT-VNTSC-FTA-98-6, 1998. Table 2-1
[b] Autoignition temperature is the lowest temperature at which a fuel will ignite an external source of ignition.
[c] Ignition limit is the range of concentrations within which the fuel will ignite, if an ignition source is present.
[d] Diffusion coefficient is used to determine the rate at which the fuel disperses (the higher the coefficient, the faster the rate).
[f] Hydrogen Energy System: A Permanent Solution to Global Problems. T. Nejat Veziroglu. University of Miami. Coral Gables, Fl.
[f] http://www.mst.dk/udgiv/publications/2002/87-7972-280-6/html/app17_eng.htm
All other values from DOE Alternative Fuels Data Center; http://www.afdc.doe.gov/.

One example of how a safety investigation can ensure minimal risk was demonstrated in the introduction of composite tanks into light duty demonstration vehicles.

Figure 3.7.1. Hydrogen Storage Tank Crash Test

Analysis indicated that the risk was only minor from rear end collisions when these tanks were used in early demonstration vehicles. To determine if the use of these composite tanks was within accepted safety parameters, a demonstration was planned. A composite tank was installed as an after market conversion in a commercial light duty vehicle. As shown in Figure 3.7.1, this vehicle was then suspended by a crane 90 feet.

This vehicle was dropped, simulating a rear collision. The analysis predicted that the vehicle would be destroyed but the tank would survive with no leaks. As shown in Figure 3.7.2, the tank survived the crash and no measurable leaks were detected.

Figure 3.7.2. Hydrogen Storage Tank After Crash Test

A complete safety evaluation before the hardware is validated will ensure that each project will achieve the highest safety standard. This safety plan is integrated into this Multi-Year RD&D Plan because of the importance the DOE places on maintaining safe working conditions. This document will list general objectives that must be met in a project or proposal, but will not outline the detailed steps that must be completed in a thorough safety plan. The responsibility of selecting and justifying the specific safety methodology and falls upon the principal investigator and related research groups. There are standard practices for the qualification of safety hazards, and the investigators must choose which approaches best fit their project. Although the Hydrogen, Fuel Cells & Infrastructure Technologies Program does not require specific methodologies, all proposals are expected to include safety analyses and available data. The use and communication of effective safety practices are essential criteria in the selection of supported projects.

The worst-case failure of safety procedures is an unanticipated catastrophic failure. For this reason, every possible failure or combination of failures, from the most benign to the most severe, must be considered and analyzed. Over a period of time, a number of safety mishaps are to be expected. The design of an accident-free system or process is prohibitively expensive and nearly impossible to develop. Hydrogen has a long history of safe use in the chemical, manufacturing, and utility industries; however, as a large-scale energy carrier in the hands of the general public, it creates safety issues unique to energy projects. As such, a risk-based approach or systematic method of safety appraisal is required. Although not all mishaps can be prevented, risk of the most severe failures must be eliminated.

4.7.3 Approach

The Safety program element focuses on the following activities:

- Determining the physical and chemical properties of hydrogen and whether they are accurately reflected in hydrogen's safety classification.
- Conducting safety reviews of current and future projects, including practices and procedures.
- Developing and publishing a comprehensive database on safety, including component reliability, sensors, and hydrogen releases.

The Hydrogen, Fuel Cells & Infrastructure Technologies Program believes a comprehensive safety plan is a necessary step in the safe operation, handling, and use of hydrogen in all projects, serve as an example for continued safe operations throughout the hydrogen industry, provide experimental data on hydrogen system failures, and ensure that the public's perception of hydrogen safety will improve.

The plan would include requirements to be met by all project principal investigators during the proposal and execution phases of the project. These requirements include developing the methodology for ensuring safe hydrogen use, mitigating risks, and communicating results.

The purpose of a risk mitigation plan is to outline and minimize the risks that hold the greatest potential for harm. It is also used in the transfer of situations from high to lower risk levels. It is essentially an extension of the failure analysis. A typical product of these analyses is a prioritized list of safety aspects that require action. A risk mitigation plan provides detailed design and operational modifications for each item on that list. Typically, a discussion of mitigation measures, a cost-benefit analysis, and an implementation strategy are included. Detailed resources for developing a risk mitigation plan are available from traditional industry sources.

The communication plan is an outline of reports that are made when an incident occurs. A reportable incident is broadly defined as a failure that results in damage to personnel, equipment, or the environment. The magnitude of these risks can vary widely, and some discretion is left to the investigator to propose how to report them. However, certain incidents are reportable under any conditions:

- Any failure that results in a modification to any part of the risk assessment
- Any failure that results in injury or loss of life
- Any failure that results in downtime to process equipment
- Any failure that results in a system-wide shutdown

Since at this level of development, "failures" can often yield more valuable information than planned experiments, these data need to be reported.

The data collection/technical program plan for safety will ensure that uniform safety practices are implemented throughout the Hydrogen, Fuel Cells & Infrastructure Technologies Program. Currently, safety practices are independently incorporated into hydrogen projects through funding requirements; however, a systematic method of safety assessment reduces the likelihood that a potential risk may be overlooked. This assessment allows a consistent measure of safety across all supported hydrogen projects.

A requirement outlined by the safety objectives is the completion of a preliminary safety assessment by the principal investigator. This assessment will be part of the response to a solicitation or funding action before an award is made. Within 6 months of award, a complete safety assessment must be performed as part of the contractual agreement. The Program will qualify the safety procedures that are outlined in the assessment. Because there are numerous methods for the effective assessment, mitigation, and communication of safety hazards, the Program does not require a specific method. Each project's proposal will be evaluated for its thorough investigation and reporting of safety hazards. Although a failure analysis, risk mitigation and communication plans are required, the approaches will be the responsibility of the individual projects. A preliminary failure mode and effects analysis (FMEA) will be expected for all project proposals. After supported projects are selected, investigators will be expected to submit detailed risk mitigation and communication plans, as well as a more detailed failure analysis.

The assessment of failures requires an accumulation of design and engineering knowledge as well as operations experience. To complete a "bottoms up" evaluation, component failure databases are especially useful. The Hydrogen, Fuel Cells & Infrastructure Technologies Program will fund investigators and research groups to initiate a survey of any published data on hydrogen and hydrogen systems to establish a database and make this information available. The accumulation of this information, including new practices that have been established to comply with the development of voluntary standards, will be published in a Handbook of Best Management Practices for safety.

A good measure of a safe hydrogen project is its insurability, and an important step is to quantify risks. The Safety and Codes and Standards subprograms will coordinate with the Education program element to develop training materials and practices that DOE can use to foster the insurability of projects and technologies. A thorough safety plan will serve as a basis on which the risks associated with a technology may be measured.

The hydrogen safety plan will include the formation of a Hydrogen Safety Review Panel, which will review all supported projects, make recommendations, propose alternatives or state the need for additional analysis or reviews. This panel will provide an "independent assessment" to the funded groups, and will provide prototype documents for principal investigators to use as templates for their own risk assessment and mitigation.

3.7.4 Status

Before publishing this plan, DOE addressed hydrogen safety as a contractual requirement between funded parties, relying on existing protocols and practices by the National Laboratories, universities, and industry to review and enforce safety in their R&D projects. Larger demonstration projects were required to provide third party safety reviews after an award, but before hardware testing. Some aspects of these safety evaluations included the appropriate use of applicable model building codes and equipment standards, the use of hydrogen sensors to help detect hydrogen leaks and modeling and testing of potential leak/accident scenarios.

As the number of funded projects increased and the potential for an unplanned accident increased, members of the Hydrogen Technical Advisory Panel (HTAP) recommended a safety committee be formed. The committee's purpose was to enhance hydrogen safety in the hydrogen energy community with a major focus on DOE activities, programs, and projects.

Its objectives were to help DOE identify safety concerns, determine current status of policies, regulation, codes, standards, and guidelines, and provide a national platform to discuss critical hydrogen safety issues.

DOE, however, has not funded work specifically aimed at hydrogen system safety except some preliminary studies on vehicles. Industry typically uses a risk-based approach for new designs, but many such efforts are proprietary. Historical practice in government and industry has resulted in methodologies to ensure hydrogen system safety, but the use of such safety practices may be cost-prohibitive since they were not designed for large- scale commercial practice.

Complete System Safety

A complete safety plan identifies quantitative and qualitative risks. These risks are evaluated to determine whether they could result in a primary or secondary failure of the components or system and the associated risk of injury to personnel.

All potential hazards in a hydrogen production, utilization, or storage system are identified and analyzed, as well as any system aspects that may be adversely affected by a failure. These aspects include:

- **Personnel**. The paramount concern of a safety assessment is to identify and mitigate hazards that pose a risk of injury or loss of life to personnel. A complete safety assessment considers those personnel who are directly involved in a hydrogen process and others at risk.

- **Equipment**. Another important consideration is to prevent damage to or loss of equipment. Damage to equipment can be both the cause and the result of incidents. An equipment failure can result in collateral damage to nearby equipment, which can trigger additional equipment failures. A complete safety plan must consider and minimize any risk of equipment damage.

- **Environment**. A safety plan also considers damage to the environment. Any aspect of a natural or built environment that can be harmed by a failure is identified and analyzed. A qualification of the failure modes resulting in environmental damage is included in the safety plan.

Another important consideration is uniformity in safety analyses, both within a project and across all Program-supported activities. Uniformity is expected within each project, with similar risk mitigation and reporting methodologies used for every aspect.

Designing a system generally includes several general safety requirements. The following design components form part of a common sense approach to system design, with specific requirements, and represent common state-of-the-art safety practices:

- **Minimal-Risk Design**. Significant effort should be made to eliminate risk in system designs. All system components should be selected with safety as a primary concern and integrated into the system according to the manufacturer's guidelines. Deviations from manufacturer suggested use should be supported and documented by sound engineering judgment and data and they are subject to review by the Safety Panel.

- **Safety Devices/Fail-Safes/Interlocks**. Safety devices, including sensors, fail-safes, and interlocks, are integral to any hydrogen process and must be included in all system designs.

- **Safety Training**. Personnel must be trained in safety methods and must understand the potential failure modes and responses. As practical experience is highly effective in failure situations, hands-on experience and training are priorities. A first responder curriculum must be developed and integrated into the Education program element activities to assist local officials.

A commonly accepted method for evaluating and providing for safety includes FMEA with fault tree analysis and a risk mitigation and communication plan.

A FMEA is an established standard for reliability engineering. Its purpose is to analyze every design component for safety hazards and demonstrate an understanding and anticipation of single or multiple component failures. The most important objective of a FMEA is to prevent common cause problems. If a failure occurs, a FMEA is used to minimize its effects. In a sense, the FMEA is a reliability tool as well as a safety tool, as it can help to identify areas within a system that are prone to failure.

A FMEA can be preformed via two different approaches. The hardware, or component, analysis identifies and analyzes the ramifications of component failures. This method is a bottom-up approach, wherein failures are initiated on the subsystem level. The functional approach is a top-down method, more suitable when specific components have not yet been chosen. Either approach is acceptable. The development of the FMEA is a continuous process, and the document should evolve as the system design changes.

System engineers must provide the pertinent information to properly conduct a failure analysis that includes:

- Component specifications and configurations
- Component interaction information
- Operating procedures
- Equipment types

Information from early projects or Technology Validation program element activities are especially effective because of the system integration. Various methodologies can be used to create a FMEA, and numerous FMEA guides are available from traditional industry sources.

3.7.5 Challenges

Developing a comprehensive safety plan is challenging. First, the database of safety information on many hydrogen components and systems that would be used in a hydrogen infrastructure is limited to industrial practice. This scientific and technical knowledge may also be limited because each company that produces and uses large quantities of hydrogen has established training practices that must be followed for liability reasons. These companies use these practices because they comply with federal regulations and are accepted by their insurance providers. Any new information may not be published because it is considered competition sensitive or proprietary.

Second, there is currently a general lack of understanding of hydrogen and hydrogen system safety needs among local government officials, fire marshals, and the general public. Those who are informed use the published information in many handbooks or training programs, which may be limited or inaccurate. For example, although hydrogen is listed as a Class B hazard, some of the data used to classify hydrogen could not be reproduced in the DOE laboratories.

Third, there is no comprehensive Handbook of Best Management Practices for hydrogen safety. DOE attempted to resolve this deficiency by collaborating with Natural Resources of Canada to produce a Hydrogen Sourcebook, that included safety-related issues. Many found this resource too complicated and too detailed. Once mandatory reporting is established for safety and reliability, the presentation of this information could likewise become very complex and require extensive training to adequately convey it to the appropriate government officials.

Finally, all the data collected must be of high quality, and in all cases defensible to meet the needs of insurance providers.

3.7.5.1 Targets

Table 3.7.2 summarizes the technical objectives associated with the Safety program element.

Table 3.7.2. Targets for Hydrogen Safety

1) Release historical dossier on safety. (Objective 1, Task 1)
2) Incorporate safety protocols into solicitations. (Objective 1, Task 2)
3) Conduct first meeting of Hydrogen Safety Review Panel. (Objective 1, Task 3)
4) Draft R&D plan for safety related tests and evaluations. (Objective 1, Task 4)
5) Implement R&D needs for safety into the spend plan, procurement plan, and budget. (Objective 1, Task 4)
6) Accept terms and conditions by the Procurement Office. (Objective 2, Task 5)
7) Incorporate selection criteria into all future procurements. (Objective 2, Task 6)
8) Incorporate safety criteria into the annual review process in each review area. (Objective 2, Task 7)
9) Obtain the first "hit" on public access Database on Safety. (Objective 3, Task 8)
10) Complete first 10 safety assessments. (Objective 3, Task 9)
11) Receive acceptance by Peer Review Team on the Handbook of Best Management Practices. (Objective 3, Task 10)

3.7.5.2 Barriers

This section details the barriers that must be overcome to achieve the goals and objectives of the Safety program element.

A. Limited Historical Database for Components. Only a small number of hydrogen technologies, systems and components are in operation. As such, only limited data are available on the operational and safety aspects of these technologies, and the materials from which they are fabricated.

B. **Access to Industry Proprietary Data**. Hydrogen technologies, systems, and components are still in the pre-commercial development phase. As such, only limited data are available on the operational and safety aspects of these technologies. Sharing safety data is required for projects funded under the Hydrogen, Fuel Cells & Infrastructure Technologies Program.

C. **Validation of Historical Data**. The historical data used in accessing safety parameters for the production, storage, transport, and utilization of hydrogen are several decades old. Validation of these data and an assessment of their use may prove useful in the development of a hydrogen infrastructure.

D. **Technical and Scientific Understanding of Systems Limits the Value of Protocols**. There is a need to better understand the fundamental limits of hydrogen systems.

E. **Obtaining Industry Input and Consensus**. Because of the status of hydrogen technologies and the competitive nature of this industry, individuals and their companies are unwilling to share information or develop consensus opinions on safety. Therefore, sharing information upon request by the Safety Review Panel will be a contractual obligation for participation in the Hydrogen, Fuel Cells & Infrastructure Technologies Program.

F. **Liability Issues**. Lawsuits and insurability are serious concerns that could affect the commercialization of hydrogen technologies.

G. **Lack of Understanding among Procurement Officials**. DOE procurement officials have little understanding of hydrogen safety issues, but will need to include these parameters into solicitations.

H. **General Counsel Acceptance of Procurement Requirements**. DOE General Counsel will need to accept the recommended procurement requirements.

I. **Variation in Standard Practice of Safety Assessments for Components and Energy Systems**. Variations in safety practices and risk assessments are inevitable and could result in accidents.

J. **Continued Project Follow-On is Not Prevailing Safety Practice**. Safety practices will need to be maintained throughout the duration of the projects, which is not the prevailing approach.

K. **Existing Data are Proprietary or Not Easily Accessible**. In many cases, critical safety data and information are not shared because they are proprietary or not readily accessible.

L. **Expense of Data Collection and Maintenance**. Developers may choose not to pursue the detailed collection and maintenance of all safety data and information because of the added expense.

M. **Quality of Data**. In cases where safety data are routinely or semi-routinely collected, the quality of the data may not meet the exacting collection standards needed to communicate safety assurance.

N. Lack of Mandatory Reporting Requirements for Past Hydrogen Incidents. There are currently no mandatory reporting requirements for hydrogen safety incidents; consequently, there is little specific information on these incidents.

3.7.6 Task Descriptions

Task descriptions are presented in Table 3.7.4.

Table 3.7.4. Technical Task Descriptions

Task	Description	Duration/Barriers
1	**Develop potential accident scenarios and key data needs** The necessary first step in providing a safety plan is to identify what can go wrong. To accomplish this, a classification system to assess data and an appropriate search protocol must be developed. In addition, a methodology for prioritizing the information will be established. The dossier of accident scenarios will then be constructed and released.	2 Quarters/Barriers A, C
2	**Establish the protocol necessary to identify failure modes and mitigate risk** Since the Hydrogen, Fuel Cells & Infrastructure Technologies Program will place the impetus for identifying potential failure modes and mitigating risk with the project principal investigators, the program must provide the protocol. A literature search will be performed for failure modes and risk mitigation in similar systems, and a protocol will be drafted. A workshop will be held with industry experts to review and revise the protocol. The consensus protocol will then be released, and will become part of program solicitations.	3 Quarters/Barriers A, C
3	**Assemble a Hydrogen Safety Review Panel** A panel of experts will provide guidance on hydrogen safety to the funded projects. The panel will consist of industrial stakeholders (transportation original equipment manufacturers, energy companies, industrial gas companies and power generation companies), government agencies (DOE, DOT, NASA) and representative principal investigators from the national laboratories, universities, and industry. This panel will review each project annually, focusing on safety concerns. It will also review new projects at inception, paying particular attention to standard operating procedures (SOPs). After the panel of experts is assembled, a charter will be developed, and business practices (safety reviews, SOP reviews) will be established.	4 Quarters/Barriers B, D, E

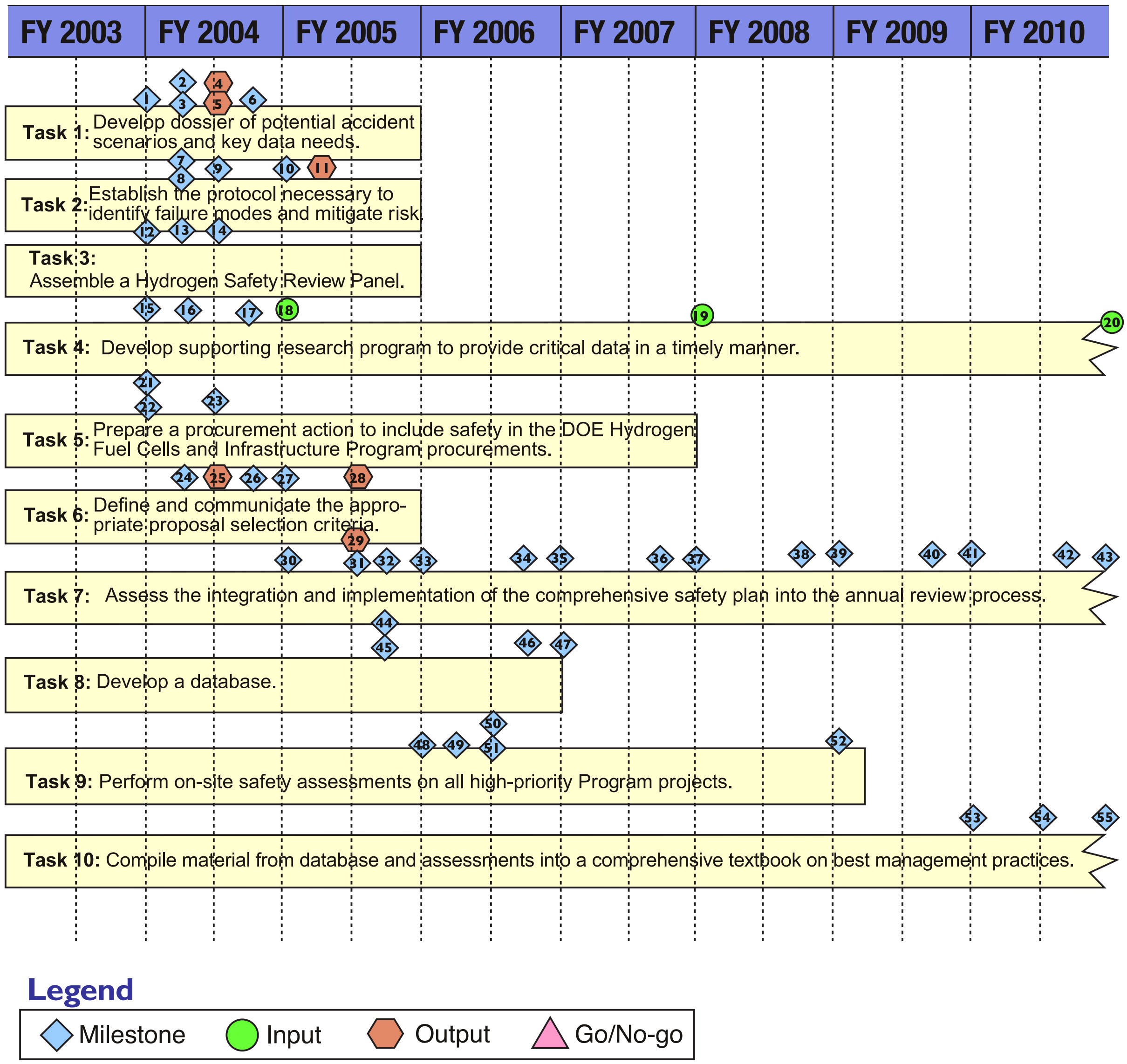
4	**Develop supporting research program to provide critical data in a timely manner** Some areas of hydrogen safety, which are as yet undefined, have insufficient data. A supporting research program will be developed to provide the missing data. The literature search performed to identify failure modes will be evaluated to identify the areas where additional research is necessary.	5 Quarters/Barrier C
5	**Prepare a procurement action to include safety in all program procurements** For a plan for incorporating safety into all program procurements to be accepted, General Counsel must be assured that the requirements are both reasonable and non-exclusionary for a government procurement. The task will therefore involve gathering and reviewing appropriate data to ensure the inclusion of hydrogen safety in these procurements. The terms and conditions for DOE procurements that include safety reviews will be finalized. ▪ Develop presentation with supporting data. ▪ Assure General Counsel that requirements are reasonable and nonexclusionary.	5 Quarters/Barriers F, G
6	**Define and communicate proposal selection criteria** To accomplish this task, a meeting of the Hydrogen Safety Review Panel will be convened. At this time, draft criteria and procurement plans will be developed. Following this, the procurement plan will be presented to the DOE contracting officer and the DOE project engineer for concurrence.	6 Quarters/Barriers F, G, H
7	**Assess the integration and implementation of the comprehensive safety plan into the annual review process** The criteria for safety evaluation at the Annual Peer Review will be established and implemented. The Safety Review Panel will incorporate the safety-related comments of the Peer Review Team into its business practices on an annual basis.	10 Quarters/Barrier H
8	**Develop a database** The task will be accomplished first by developing the format for accessibility and use of the database, and by establishing the criteria for all collected data. Working with industry to ensure adequacy and quality, DOE will inventory existing data. Following the release of the database, data gathering from new sources will continue, and the database will be periodically updated.	15 Quarters/Barriers J, K, L, M

9	**Perform on-site safety assessments on all high-priority program projects** Site visits to the locations of various program projects will provide details on the steps taken to ensure safe practices by the project leaders. The safety assessments will be similar to the technical evaluations of projects effort currently being performed by the program. Although site visits are important and will be included, validation project sites will likely involve a team of evaluators who will cover all aspects of safety practices for the entire system. The validation project evaluations will provide the majority of the input for the Best Management Practices Handbook for hydrogen system safety. The safety assessment task will be accomplished by first reviewing existing safety protocols, and then developing separate reporting formats for the validation projects and the R&D projects. The projects will then be prioritized and the site visits will begin. By September 2008, all high-priority assessments will be completed, and reports will have been written. Safety assessments of other projects will continue and will be included in the handbook. Even after completion of the original handbook, safety evaluations will continue, revisiting old projects if necessary, and adding new ones. Since the handbook is to be a living document, information gathered here will be included in later versions.	23 Quarters/Barriers J, K, L, M
10	**Compile material from database and assessments into a comprehensive textbook on best management practices** The actual compilation of the handbook will be the subject of the final task. Data for the handbook will come from the database (Task 8) and the safety assessments (Task 9). First, a team will be assembled to prepare the handbook. The team will compile a draft handbook, and submit it to a review team. (This may or may not be the same group as the Safety Review Panel discussed in Task 3; the makeup of this review team will be determined during the task performance.) After comments are received from the review team, the final Best Management Practices Handbook for Hydrogen Safety will be completed.	31 Quarters/Barriers J, K, L, M
Note: The total duration of the program planning period is 32 quarters; tasks that begin before this period or continue beyond it do not reflect durations outside the planning period.		

3.7.7 Milestones

Figure 3.7.3 shows the interrelationship of milestones, tasks, and outputs to other subprograms for the Hydrogen Safety program element for FY 2004 through FY2010. This information is also summarized in Table B.7 in Appendix B.

Figure 3.7.3. Hydrogen Safety R&D Network



For chart details see next page.

1. Review existing data and develop classification systems for assessment.
2. Develop, in collaboration with NASA, DOT, and DOC, a search protocol on component and system safety.
3. Develop prioritization methodology.
4. Output to Storage: Safety requirements and protocols for bulk storage
5. Output to Storage: Safety requirements and protocols for on-board storage
6. Complete and distribute the potential accident scenarios for review and agreement.
7. Draft protocol.
8. Workshop to review protocol.
9. Release consensus protocol.
10. Perform literature search.
11. Output to Technology Validation: Safety requirements and protocols for vehicle safety and stationary refueling
12. Assemble panel of experts in hydrogen safety to provide expert technical guidance to funded projects.
13. Develop charter for Safety Review Panel.
14. Establish business practices.
15. Prepare draft R&D needs whitepaper.
16. Finalize draft of R&D needs whitepaper.
17. Assess literature survey of failure modes for areas of additional study and research.
18. Input from Education: Public perceptions assessment
19. Input from Education: Public perceptions assessment
20. Input from Education: Public perceptions assessment\
21. Gather and review data to support the inclusion of hydrogen safety in procurements.
22. Present procurement request to general counsel.
23. Finalize terms and conditions for DOE procurements that include safety reviews.
24. Convene a meeting of Hydrogen Safety Review Panel.
25. Output to Production: Safety requirements and protocols for refueling
26. Draft criteria and procurement plan.
27. Present procurement plan to the contracting officer (and project engineer for concurrence).
28. Output to Delivery: Safety requirements and protocols for pipelines and transit
29. Output to Education: Training materials for testing and certification for engineered systems
30. Incorporate programmatic review comments into Safety Review Panel's business practices.
31. Establish annual review criteria for safety.
32. Conduct review of projects.
33. Incorporate programmatic review comments into Safety Review Panel's business practices.
34. Conduct review of projects.
35. Incorporate programmatic review comments into Safety Review Panel's business practices.
36. Conduct review of projects.
37. Incorporate programmatic review comments into Safety Review Panel's business practices.
38. Conduct review of projects.
39. Incorporate programmatic review comments into Safety Review Panel's business practices.
40. Conduct review of projects.
41. Incorporate programmatic review comments into Safety Review Panel's business practices.
42. Conduct review of projects.
43. Incorporate programmatic review comments into Safety Review Panel's business practices.
44. Develop format for accessibility and use.
45. Establish reporting criteria for all collected data.
46. Inventory existing data with industry and government for adequacy and quality.
47. Populate the database.
48. Review existing safety protocols.
49. Develop reporting format for validation projects.
50. Develop reporting format for R&D projects.
51. Establish priorities for safety assessments.
52. Complete assessments for high-priority projects.
53. Assemble team to prepare Best Management Practices Handbook.
54. Complete draft of Handbook.
55. Complete final peer-reviewed Handbook.